Atmospheric Infrared Sounder (AIRS) Level 1B Visible, Infrared and Telemetry Algorithms and Quality Assessment (QA) Processing Requirements

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Version 2.3

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1   Introduction

1.1 Scope of Document

This document describes the required inputs and outputs of the Level 1B processing software. This document is generated by the AIRS Calibration Team to facilitate the development of the L1B software and the L1B testbed. It allows us to communicate the current algorithmic approach for all L1B products and provides a place to identify changes if needed. It is possible that the L1B will do more than what is stated here. This is not envisioned as a problem provided that the basic capability outlined in this document is satisfied and that additional processing does not unduly tax the overall processing infrastructure.

This document is designed to meet the requirements of the L1B ATBD (reference 1). It also satisfies the requirements in the AIRS/AMSU/HSB QA plan (reference 11) and the requirements of the AIRS Visible and Infrared In-Flight Calibration Plan (reference 2).

This document focuses on the algorithms for the L1B to convert digital numbers into calibrated radiances. It also presents the algorithms and requirements for the Quality Assessment (QA) indicators to be generated by the L1B. Requirements for post-processing of the L1B are presented in the AIRS In-Flight Calibration Plan, Reference 2.

1.2 Reference Documents

The following documents are referenced within this document:

1. "AIRS Level 1b Algorithm Theoretical Basis Document (ATBD) Part 1 (IR)", H. Aumann, et. al., November 10, 2000.
2. "AIRS Visible and Infrared In-Flight Calibration Plan", AIRS Calibration Team Version 2.0, May 2001
3. "Telemetry/Calibration Handbook", JPL-D-16920, Lockheed Martin Infrared Imaging Systems Inc, Jet Propulsion Laboratory, Version 7, July 26, 1999
4. "Command Handbook Pre-Flight Model/Module", SE004-05, Lockheed Martin Infrared Imaging Systems Inc, Jet Propulsion Laboratory, Version 5, October 1, 1999
5. "Scan Angle Dependent Radiometric Modulation due to Polarization for the Atmospheric Infrared Sounder (AIRS)", T. Pagano, et. al, SPIE 4135-14, August 2000.
6. "Polarization use in AIRS radiometry", T. Pagano, April 16, 2001, ADF-486A
7. "Radiometric Coefficients for L1B. Version 1.1 Revised", T. Pagano, April 16, 2001, ADF-487A
8. "Results of AIRS PFM Cross Axis Scan Tests Pre-Vibe", T. Pagano, April 23, 1999, ADF-324A
9. "Results of AIRS PFM Cij Measurements", T. Pagano, March 15, 1999, ADF-312
10. "Definition of the 3 pairs of channels for monitoring scene homogeneity", G. Aumann, January 22, 2001, ADF-524
11. "AIRS/AMSU/HSB Data Processing and Data Products Quality Assessment Plan", Version 2.0, E. Fetzer, et al., June 12, 2001, JPL D-20748
12. "IR Calibration Properties for L1B; Version 1.3", T. Pagano, ADF 485, January 31, 2001.

1.3 Changes

1.3.1 Changes since version 2.0

1. A new algorithm was implemented for calculating the **AutomaticQAFlag** (Section 4.2.2).
2. A new "pop" detection algorithm was implemented (Table 3 and 4).

3. The Lunar Filtering algorithm was refined after testing with Operational data (Section 6.2.1.4).

4. Two new radiometric QA parameters were implemented: **input_space_signals** and **input_bb_signals** (Section 6.2.3 and 6.4.3).

5. The **NeN** algorithm was refined to more accurately estimate the scene noise (Section 6.5.1).

6. The nomenclature of the QA parameters used to monitor the scene uniformity has been changed as follows: "cij_water" → "Rdiff_lwindow," "cij_window" → "Rdiff_swindow," and "cij_CO2_R_Branch" → "Rdiff_strat." (Section 8).

2   Overview

The main functions of the Level 1B is to convert digital numbers from the science data in Level 1A into calibrated radiances for all footprints and all channels and assign spectral frequencies. This involves application of calibration algorithms and coefficients calculated within the Level 1B software. Another major function of the L1B is to calculate the spectral centroids for all the channels; these are included in the QA indicators.

Appendix 1 gives the entire list of QA indicators required of the Level 1B infrared data.

3   Data Types and Structures

Data are to be presented in several different ways in the L1B data file. Data are presented either once per granule, once per scan, or once per footprint in most cases. Some data are presented once per calibration footprint or 6 times / scan. Data can be string, floating point or integer and of 8 bit, 16 bit or 32 bit in length. The specific data type for each QA indicator and the required frequency of occurrence and data type are presented in Appendix 1.

In addition to the standard data types, there are two types of engineering structures to be presented from the L1B. These types allow the most information to be conveyed for each QA indicator possible without redundant or non-useful information. The Limited Engineering structure provides statistics on the QA indicator and information about the number of occurrences of "out-of-limit" conditions. The Unlimited Engineering structure is the same as the limited engineering structure except no limit results are reported. All statistical values are 32 bit floating point numbers, and all counts of occurrences are 32 bit integer values. All values are reported per granule unless otherwise specified.

Limits are to be provided for all QA indicators which are to be reported in the Limited Engineering Structure. These will be highlighted in the subsequent sections.

Note: Types "Color Counts" and "Fit Deviation" from earlier versions are no longer required.

3.1 Values Common to Limited and Unlimited Engineering Structures

Min: Minimum of all in-range values within the granule.

Max: Maximum of all in-range values within the granule.

Mean: Average of all values within the granule.

Dev: Standard Deviation of all values within the granule

Max_track: GeoTrack Index where max was found

Max_xtrack: GeoXTrack Index where max was found

Min_track: GeoTrack Index where min was found

Min_xtrack: GeoXTrack Index where min was found

Num_bad: Number of occurances of invalid data as determined by L1A (BAD_FLOAT, –9999). within a granule.

3.2 Values Specific to Limited Engineering Structure

Num_in: Number of occurrences of in-range conditions of all meaningful samples within a granule.

Num_lo: Number of occurrences of out-of-range low conditions of all meaningful samples within a granule.

Num_hi: Number of occurances of out-of-range high conditions of all meaningful samples within a granule.

"Meaningful" samples are those that are not considered "bad".

range_min: Minimum in-range value (low limit).

range_max: Maximum in-range value (high limit).

4 Data Integrity

The AIRS Calibration Team requires a complete set of Quality Assessment (QA) Indicators for status and trending of the AIRS calibration performance. Table 1 gives the complete list of Metadata/QA indicators and whether they are passed directly from the L1A or generated by the L1B processor. For those QA indicators generated by the L1B, we have included the section where the requirements are defined.

Table 1a. Granule-level Metadata/QA indicators required to be generated by the L1B PGE, and the section where discussed in this document (except for those parameters passed directly from L1A).

Primarily From L1A		Primarily Radiometric		Primarily Spectral	
Name	Section	Name	Section	Name	Section
processing_level	Fixed	CalGranSummary	4.2.6	spectral_TAI	7.1.6
instrument	Fixed	CalChanSummary	4.2.5	spectral_TAI_prev	7.1.6
DayNightFlag	1A	ExcludedChans	4.3	nominal_freq	7.1.6
AutomaticQAFlag	4.2	NeN	6.5.3	spectral_freq	7.1.6
NumTotalData	4.2	DCR_scan	6.2.3	spectral_freq_unc	7.1.6
NumProcessData	4.2	input_scene_counts	6.1.3	spectral_freq_prev	7.1.6
NumSpecialData	4.2	input_space_counts	6.2.3	spectral_freq_prev_unc	7.1.6
NumBadData	4.2	input_space_diffs	6.2.3	spec_shift_upwell	7.1.5
NumMissingData	1A	input_bb_counts	6.4.3	spec_shift_unc_upwell	7.1.5
NumLandSurface	1A	input_spec_counts	7.1.4.4	spec_fl_upwell	7.1.5
NumOceanSurface	1A	input_space_signals	6.2.3	spec_fl_unc_upwell	7.1.5
node_type	1A	input_bb_signals	6.4.3	SpectralFeaturesUpwell	7.1.2
start_year	1A	input_bb_temp	6.4.3	spec_feature_shifts_upwell	7.1.4
start_month	1A	input_bb_temp1	6.4.3	spec_feature_corr_upwell	7.1.4
start_day	1A	input_bb_temp2	6.4.3	spec_feature_sharp_upwell	7.1.4
start_hour	1A	input_bb_temp3	6.4.3	spec_feature_resid_upwell	7.1.5
start_minute	1A	input_bb_temp4	6.4.3	spec_iter_upwell	7.1.5
start_sec	1A	input_spec_temp	5	spec_feature_contrast_stats	7.1.4
start_orbit	1A	input_ir_det_temp	5	spec_clim_select	7.1.2
end_orbit	1A	input_grating_temp_1	5	spec_shift_pary	7.2.4
orbit_path	1A	input_grating_temp_2	5	spec_shift_unc_pary	7.2.4
granule_number	1A	input_entr_filt_temp	5	spec_fl_pary	7.2.4
num_scansets	1A	input_opt_bench_temp_2	5	spec_fl_unc_pary	7.2.4
num_scanlines	1A	input_opt_bench_temp_3	5	SpectralFeaturesPary	7.2.1
start_Latitude	1A	input_scan_mirror_temp	5	spec_feature_shifts_pary	7.2.3
start_Longitude	1A	input_chopper_phase_err	5	spec_feature_corr_pary	7.2.3
start_Time	1A	PopCount	N/A	spec_feature_sharp_pary	7.2.3
end_Latitude	1A	offset_stats	6.2.3	spec_feature_resid_pary	7.2.4
end_Longitude	1A	gain_stats	6.4.3	spec_iter_pary	7.2.4
end_Time	1A	rad_stats	6.1.3	ave_pary_spectrum	7.2.2
eq_x_longitude	1A	NumRefChannels	4.3		
eq_x_tai	1A	RefChannels	4.3		
orbitgeoqa	1A	rad_scan_stats	6.1.3		
num_satgeoqa	1A	DCRCount	N/A		
num_glintgeoqa	1A				
num_moongeoqa	1A				
num_ftptgeoqa	1A				
num_zengeoqa	1A				
num_demgeoqa	1A				
num_fpe	1B				
LonGranuleCen	1A				
LatGranuleCen	1A				
LocTimeGranuleCen	1A				
granules_present	1A				

Primarily Spatial	
Name	Section
Rdiff_swindow_M1a_chan	8
Rdiff_swindow_M2a_chan	8
Rdiff_lwindow_M8_chan	8
Rdiff_lwindow_M9_chan	8
Rdiff_strat_M2b_chan	8
Rdiff_strat_M1b_chan	8

Table 1b. Per-scan and per-footprint QA indicators.

Per Scan		Per–Footprint	
Name	Section	Name	Section
satheight	1A	scanang	1A
Satroll	1A	ftptgeoqa	1A
Satpitch	1A	zengeoqa	1A
Satyaw	1A	demgeoqa	1A
satgeoqa	1A	satzen	1A
glintgeoqa	1A	satazi	1A
moongeoqa	1A	solzen	1A
nadirTAI	1A	solazi	1A
sat_lat	1A	sun_glint_distance	1A
sat_lon	1A	topog	1A
scan_node_type	1A	topog_err	1A
Glintlat	1A	landFrac	1A
Glintlon	1A	landFrac_err	1A
CalScanSummary	4.2	state	1A
CalFlag	4.2	Rdiff_swindow	8
SpaceViewDelta	6.2.3	Rdiff_lwindow	8
spaceview_selection	6.2.3	Rdiff_strat	8
OpMode	1A	SceneInhomogeneous	8
Gain	6.4.3		
DpCircCounts	1A		

4.1 Key Items Passed Directly from L1A

A fundamental requirement prior to processing any data is to know the instrument state. This is because the instrument could be off or in a calibration mode or some other state that would make processing highly restricted. The L1A passes the critical instrument modes and states to the L1B through the OpMode word from the telemetry. Further details on the OpMode word can be found in references 3 and 4.

The "state" flag is generated by the L1A for every earth scene footprint and can be 0:Process, 1: Special, 2: Erroneous, 3: Missing. It is used primarily by the Level 2 processing software. We propose to only modify the state flag to "Erroneous" for all footprints in the scan if the OBC Blackbody and all space views are "bad" within the corresponding scan.

Table 1 identifies which of the QA indicators are passed from L1A without modification. Of all these, only the state flag is modified before output into the L1B data files. Of the remainders, only the OpMode, LonGranuleCen, LatGranuleCen and LocTimeGranuleCen, sat_lat, sat_lon, and nadirTAI, are required by the AIRS Calibration Team. The rest are required for Level 2 processing.

4.2 Flags Generated in L1B

4.2.1 NumXXXData

Five QA flags are to be generated in L1B to summarize the state flag in the granule. They are denoted NumXXXData and are defined in Table 2.

Table 2. Definition of the NumXXXData QA Indicators are based on the state flag

Name	Definition
NumTotalData	Total number of data points expected in the granule
NumProcessData	Number of data points with state = 0
NumSpecialData	Number of data points with state = 1
NumBadData	Number of data points with state = 2
NumMissingData	Number of data points with state = 3

4.2.2 AutomaticQAFlag

AutomaticQAFlag will determine the overall quality of the granule. It is a string which will always be "passed", "failed", or "suspect". It is based on the fraction of good data in the granule and not on the calibration flags:

AutomaticQAFlag =

"passed" if NumProcessData $\neq$ 0 and NumSpecialData + NumBadData = 0;

"failed" if NumProcessData = 0;

"suspect" all other cases.

4.2.3 CalFlag

The CalFlag word is generated once per scan line for all 2378 IR channels. It is a bitwise variable field where each bit summarizes the QA indicators related to the bits purpose. The definition and algorithm for setting each bit is defined in table 3. A high on the individual bit denotes "fail" for that bits purpose.

Table 3. Definition of CalFlag bits. CalFlag is provided for each channel every scan.

Bit	Name	How Set (Per scan decision)	Dependency
7	Scene	overflow/underflow on scene occurred	90 earthview dn's per scan
6	Offset	overflow/underflow on SV occurred	4 spaceview dn's per scan
5	Gain	overflow/underflow on OBC BB view occurred, BB dn, signals, or temperatures per scan out of limits, BB side error	BB dn, signals and temperatures
4	pop detected	The difference between 6 corresponding calibration footprints exceed N_width_report * svd_nse	SpaceViewDelta, DCR_scan
3	DCR Occurred	Apply high to this bit for scan in granule identified by DCR_scan	DCR_scan
2	Moon in View	Flag as defined in section 6.2.1.4	Spaceview_selection
1	telemetry	Out of limit condition for telemetry in Table 5	See Table 5
0	Reserved		

4.2.4 CalScanSummary

CalScanSummary is a bitwise summary of the performance of the scan for all good channels. This flag is a logical "OR" of the CalFlag word applied over all good channels. Good channels are defined in section 4.3.

4.2.5 CalChanSummary

CalChanSummary identifies calibration performance for each channel over the whole granule. It also follows a format similar to CalFlag and CalScanSummary, but uses the granule-level QA indicators as inputs. The bit structure definition is provided in Table 4.

Table 4. Definition of bit structure for CalChanSummary Word. CalChanSummary is provided for every channel once per granule.

Bit	Name	How Set (Per granule)	Dependency
7	Scene	overflow/underflow on scene occurred	logical "or" of CalFlag Bit 7 over all scans
6	Offset	overflow/underflow on SV occurred	logical "or" of CalFlag Bit 6 over all scans
5	Gain	overflow/underflow on OBC BB view occurred, BB dn, signals, or temperatures per scan out of limits, BB side error	logical "or" of CalFlag Bit 5 over all scans
4	pop detected	The difference between 6 corresponding calibration footprints exceed N_width_report * svd_nse	logical "or" of CalFlag Bit 4 over all scans
3	Noise out of bounds	NEN Exceeds Limits for granule	NEN
2	spectral bad	Spectral fit failed or fit residuals too high	See sections 7.1.5.3 and 7.1.5.4
1	Telemetry	Out of limit condition for telemetry in Table 5	See Table 5
0	Reserved		

4.2.6 CalGranSummary

CalGranSummary is a bitwise summary of the performance of the granule for all good channels. This flag is a logical "OR" of the CalChanSummary word applied over all good channels. Good channels are defined in section 4.3.

4.3 Channel Quality Indicators

The calibration properties file, cal_props.txt, identified in table 8 contains a definition of the A and B combination used in the AIRS gain file. This is defined in more detail in reference 12. If the state is 0, both A and B detectors meet all performance criteria and the gain is an equal weighting of A and B detectors. This gives the best performance for AIRS. If the state is 1, the A side meets all criteria and the B side does not. If the state is 2 then the B side is good and the A side does not meet one of the criteria. If the state is > 2, both the A and B do not meet one or more of the criteria and are to be considered not optimal for use in L1B. Therefore:

ExcludedChans is defined as the Abstate from the Channel Properties input file to L1B (see table 8). ExcludedChans is to be echoed in the output of L1B.

"Good Channels" as referred to in this document are all channels of AIRS excluding the "ExcludedChans".

Reference channels are 3 represented channels from each of the 17 modules. There are a total of 51 reference channels. They are typically chosen as the center and two ends of the module where the channels selected have AB State ≤ 2.

NumRefChannels = 51. NumRefChannels is to be echoed in the output of L1B.

RefChannels are defined in the l1b_params.txt input file to L1B (see table 8). RefChannels is to be echoed in the output of L1B.

5   Instrument Telemetry

Several telemetry items are provided in Table 5 which must be tracked as QA indicators in the L1B . These include temperatures of the scan mirror, spectrometer, grating, optical bench, IR detectors and the entrance filter. The scan angle must also be provided the center footprint. We also track the circumvention threshold level and counts. The chopper phase error is critical to the spectral calibration of the PC bands since the chopper is at the entrance slit of the spectrometer. The telemetry are converted to engineering units in the L1A software.

The temperatures identified in Table 5 are critical to calibration stability and performance and if they go out of limits, it is required that the CalFlag, and CalChanSummary flags indicate the out of limit condition. (See prior section) Also any "glitches", or deviations from nominal by more than 0.01°, in the scan mirror angle at nadir are to be identified by setting the same bit in the same flags. Finally the same flag is to be set if the chopper phase error goes out of limits.

Table 5: Cross reference of L1B Telemetry QA Indicator and High Rate Telemetry Identification.

L1B Identification	Limited or Unlimited Structure	Set Bit 1 of CalFlag or CalChanSummary	High Rate Engineering Data Identification
input_scan_mirror_temp	Limited	Yes	ScMirrorTemp
input_spec_temp	Limited	Yes	SpTemperature
input_grating_temp_1,_2	Limited	Yes	SpGratngTemp1 & SpGratngTemp2
input_opt_bench_temp_2, _3	Limited	Yes	SpOptBnchTmp2, SpOptBnchTmp3
input_ir_det_temp	Limited	Yes	mean of FpDetTempVA, FpDetTempVB
scanang	No	Yes	FpScanAng_067 (i.e., scan angle of scene footprint 45)
input_entr_filt_temp	Limited	Yes	SpEntFiltTmp
input_chopper_phase_err	Limited	Yes	ChPhaseErr

The scanang field is an array of 119 floating point angles, one for each of the119 footprints during an AIRS scan line. They are to be assigned as identified in Table 6.

Table 6. Assignment of 119 scan angles to physical views.

Start Footprint	Stop Footprint	Physical View
1	2	Space Footprints 1 and 2
3	8	Unused
9	9	Radiometric Calibrator (OBC)
10	13	Unused
14	14	Parylene Spectral Calibrator
15	15	Unused
16	16	Photometric Calibrator (VIS Lamps)
17	22	Unused
23	112	Scene Footprints 1 to 90
113	117	Unused
118	119	Space Footprints 3 and 4

6   Radiometric Requirements

6.1 Calibration Equation

6.1.1 Algorithm

A primary function of the Level 1B software is to convert the Level 1A digital numbers into calibrated radiances. All digital numbers in the 90 Earth Scene (or Science) view footprints shall be converted to radiance units. The conversion shall follow the calibration equation given below (references 6 and 7)

$$N_{sc,i,j} = \frac{a_o(\theta_j) + a_{1,i}(dn_{i,j} - dn_{sv,i}) + a_2(dn_{i,j} - dn_{sv,i})^2}{1 + p_r p_t \cos[2(\theta_j - \delta)]}$$

where

$N_{sc,i,j}$ = Scene radiance of the ith scan and j^{th} footprint (mW/m^2-sr-cm^{-1})

i = Scan Index

j = Footprint Index (1 to 90)

θ = Scan Angle. $\theta = 0$ is nadir.

$dn_{i,j}$ = Raw Digital Number in the Earth View for the ith scan and j^{th} footprint

$dn_{sv,i}$ = Space view offset. This is an algorithmic combination of the AIRS raw space view digital numbers as defined in a subsequent section.

a_o = Radiometric offset. This is nonzero due to polarization and is scan angle dependent and is calculated as defined in a subsequent section.

$a_{1,i}$ = Radiometric gain. This term converts dn to radiance based on the radiometric gain as determined using the OBC blackbody. This is discussed in a subsequent section.

a_2 = Nonlinearity Correction. This term is determined pre-flight and is calculated as discussed in a subsequent section.

$p_r p_t$ = Polarization Product. This is the product of the polarization from the scan mirror and the spectrometer.

δ = Phase of the polarization of the AIRS spectrometer.

Note: If any of the signals from the OBC Blackbody, Space View, or Earth View are saturated or zero, the scene radiance is to be converted to a saturated value of FFFF (decimal –1).

6.1.2 Required Inputs

The terms a_o and a_1 are discussed below.

a_2 = Nonlinearity Correction Term. This term is available for all channels and is a single number that is independent of temperature of the AIRS spectrometer. It is available in a text file based on pre-flight test data.

$p_r p_t$ = Polarization Product. This is the product of the polarization from the scan mirror and the spectrometer. It is obtained from pre-flight test data and is available in a text file.

δ = Phase of the polarization of the AIRS spectrometer; it is obtained from pre-flight testing and is available in a text file.

θ_j = Scan Angle of the jth footprint and is obtained from the telemetry as defined in table 5.

sci_counts_hi = Maximum value allowed of the counts in the science data for all channels. There are 2378 values in this file; one for each channel. It is available in a text file.

sci_counts_low = Minimum value allowed of the counts in the science data for all channels. There are 2378 values in this file; one for each channel. It is available in a text file.

RefChannels = 51 Reference Channels to be used in calculations where all channels are not required.

ref_chans_ltd = 17 Reference Channels to be used when limited data sets are desired.

6.1.3 QA Indicators Output

input_scene_counts: This QA indicator provides statistics of type "limited" to the science counts on all channels. Statistics are to be made over all footprints and scans in the granule. The limits are provided and defined above: sci_counts_hi,low. (2378 / granule)

rad_stats: This QA indicator provides statistics of unlimited type on the calculated radiance for all channels over all footprints and scans in the granule. (2378 / granule)

rad_scan_stats: This QA indicator provides statistics on the calculated radiance for the reference channels for each footprint over all scans in the granule. (90 x 51 / granule)

6.2 Space View Offset, $dn_{sv,i}$

There are two versions of this algorithm. The first is a basic algorithm that simply takes the median of the selected space views. The second is an interpolation algorithm that removes drift effects. We shall code as a minimum the basic algorithm prior to launch. If time permits the interpolation algorithm can be implemented.

6.2.1 Algorithm

6.2.1.1 Basic Algorithm

There are 4 space views acquired on every scan of the AIRS. They are divided such that space views 1 and 2 are the last two footprints in the space view prior to the earth scene scan, i, and space views 3 and 4 are the first two space views after the scan. See Figure 1 below. This algorithm simply takes the median of the 8 valid space views. Valid is defined as those who are not filtered by the user defined space views, the lunar filter or the DCR filter as discussed below.

$$dn_{sv,j=1:8,i} = \{dn_{sv,3,i-1}\ dn_{sv,4,i-1}\ dn_{sv,1,i}\ dn_{sv,2,i}\ dn_{sv,3,i}\ dn_{sv,4,i}\ dn_{sv,1,i+1}\ dn_{sv,2,i+1}\}$$

$$dn_{sv,i} = median(dn_{sv,i,j}\ for\ c_j \neq 0)$$

for all footprints where c_j is a 1 x 8 matrix for each scan and is defined as 1 if the space view is useable and 0 if not useable.

6.2.1.2 Interpolation Algorithm

As an enhancement to remove drift effects, we define an interpolation algorithm to replace the basic algorithm if required. The L1B PGE shall implement this algorithm and allow it to be activated upon request by setting a user defined input flag.

For the ith scan, compute the space view offset for each footprint at time t as a linear interpolation of a weighted contribution of the space view samples from three scans as follows:

$$dn_{sv,lo} = \frac{1}{\sum\limits_{j=1:4} c_j}\left(\sum_{j=1,4} c_j dn_{sv,j,i}\right) ;\ dn_{sv,hi} = \frac{1}{\sum\limits_{j=5:8} c_j}\left(\sum_{j=5:8} c_j dn_{sv,j,i}\right)$$

$$dn_{sv,i}(t) = \frac{(dn_{sv,hi} - dn_{sv,lo})}{T_{scan}}(t - t_o) + dn_{sv,lo}$$

where t_o = time of start of scan = 0 for starters, t = time of the jth footprint in the earth view sector and T_{scan} is the scan time = 2.6667s. A maximum error in the space view signal of about 2% of the drift between space views will occur due to equal weights. This is negligible. The frame time is

$t = j$ x $T_{scan}/119$ s. There are 119 frames in the entire scan of 2.6667s.

Scan i-1　　　　　　　Scan i　　　　　　　Scan i+1

Single view of Space　　Single view of Space

$dn_{sv,3} dn_{sv,4}$ | $dn_{sv,1}$ $dn_{sv,2}$　　$dn_{sv,3} dn_{sv,4}$ | $dn_{sv,1}$ $dn_{sv,2}$

$dn_{sv,i}$ ——————— $dn_{sv,hi}$

$dn_{sv,lo}$

Earth View
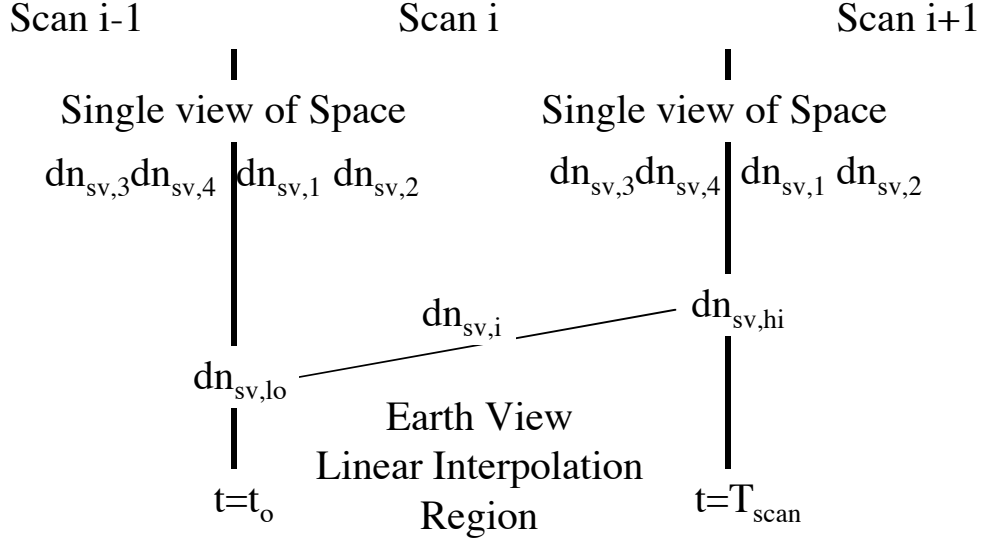Linear Interpolation
Region

$t = t_o$　　　　　　　　　　　$t = T_{scan}$

Figure 1. Relationship between each scan, i, and the 4 space view samples.

6.2.1.3 User Defined Filter

The space view coefficients c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8 are used to reject or limit the contribution of any particular space view sample from the process. c_1 through c_4 are for the space view prior to the current earth view in the scan and c_5 through c_8 are for the space view following the earth scan. Their value will be determined in orbit during the checkout phase by gathering statistics of the relative amplitudes of the four space views. The initial default value is $c_1 = c_2 = c_3 = c_4 = c_5 = c_6 = c_7 = c_8 = 1$.

6.2.1.4 Lunar Filtering

If the Moon is located close to or in the AIRS field-of-view during one or two of the cold-space-views the output of those space views will to go up for all PV channels and down for all PC channels. The level 1b algorithm tests if a contaminated space view is about to be used in the cold-space-view calculation with the following algorithm, using 15 Channels (one Reference Channel from each of the PV modules), by selecting the space view coefficients as follows:

if $(dn_{sv,j,i} - \min (dn_{sv,j,i})) > N\_width\_moon \times svd\_nse$ then $S_{j,k} = 1$

else $S_{j,k} = 0$ for $j = 1{:}8$ and for $k = 1{:}15$

where,

j is an index from 1 to 8 for each of the 8 space views used in the offset calculation and

k is an index from 1 to 15 for each of the 15 PV channels used to detect the Moon.

If the sum of $S_{j,k}$ over k is > 9 then $c_j = 0$ (i.e., the Moon is in the view) else $c_j = 1$. This is done for each of the 8 space views used in the offset calculation. If N_width_moon= 5 then this algorithm will identify a space view contamination at the noise level using 10 of the reference detectors. If this condition is detected the scan is flagged and only the remaining space views are used in the calculation.

6.2.1.5 DC Restore Filter

The analog output of each detector for modules M3 through M10 is periodically clamped by the electronics to voltage V_o during the first subsample of space view 1. This causes a discontinuity in the offset between

14

two successive scans. The time of the DCR, which occurs every 20 minutes, is identified in the downlink telemetry. The level 1b software handles the step produced by the DCR by using only 6 points corresponding to the same DCR level to calculate the effective space view offset value in the scan prior to the DCR. Since the DCR occurs in the first sub-sample of the first space view of a scan that space view measurement is unreliable and only 5 points corresponding to the same DCR level are used for the scan in which the DCR occurred. V_o has been set pre-launch to about 10% of the dynamic range by a resistor, based on experience acquired during the calibration and characterization phase, as a zero offset of the analog-to-digital converter (ADC). The value of V_o does not enter the calibration equation.

6.2.2 Required Inputs

The following data are required by the L1B software to process the space view signal and QA indicators. The inputs shall be in the form of data files to be read by the L1B.

c_i = Weighting Factors of the 8 space views to use in the space view calculation

T_{scan} = Scan Time = 2.667 s

N_width_moon = Deviation in counts above which we are to throw out the corresponding space view sample.

N_width = Multiplier times width for criteria for reporting outliers.

N_width_report = Multiplier times width for criteria for reporting to Cal_Flag.

sv_counts_hi = Maximum value allowed for each space view. One per channel.

sv_counts_low = Minimum value allowed for each space view. One per channel.

svd_nse = Standard deviation of SpaceViewDelta

6.2.3 QA indicators Output

The intent of these QA indicators, as discussed in the calibration plan is to assess the noise performance vs the orbital environment and detect instrument degradation with time. The algorithms are simple statistical relationships and will not be detailed in this document.

input_space_counts: This QA indicator is defined as the statistics on each of the four space view counts taken over all scans within a granule. The statistics for the four samples shall not be combined in this indicator. It is of type "limited" engineering data structure where the limits are set by sv_counts_hi, sv_counts_low. (4 x 2378 / granule).

input_space_signals: This QA indicator is defined as the statistics on each of the four space view signals taken over all scans within a granule. Since this parameter used in the calculation of the **NeN**, scans that were flagged as pops are omitted from the statistics. The statistics for the four samples shall not be combined in this indicator. It is of type "limited" engineering data structure where the limits are set by sv_signals_hi, sv_signals_low. (4 x 2378 / granule).

input_space_diff: This QA indicator is defined as the statistics taken on the difference between corresponding space view samples from successive scans taken over a granule. The difference provides a low pass filter on the data on the order of 1/Tscan and provides a more realistic assessment of the noise outliers within a granule. This indicator is an "unlimited" engineering structure. (4 x 2378 / granule).

This will indicate the presence of Non-Gaussian noise (pop) or some failure of the filter functions.

offset_stats: This indicator is the statistics on the $dn_{sv,i}$ over all scans within the granule and for all channels as calculated above. It is of type unlimited. (2378 / granule)

spaceview_selection: This QA indicator identifies for each scan the condition of space view samples used in the offset calculation that result from the filtering. There are to be 8 bits in this word: One bit for each of the 8 space views used in the algorithm for each scan.

SpaceViewDelta: The median of the spaceviews immediately following the scan line, minus the median of the space views immediately preceding the scan line.   The limits of this value are checked in the generation of the **CalFlag** where the limits are set by N_width_report x NE_DN. When a limit is exceeded for each scan line, it must be reported in the appropriate bit of the CalFlag unless a DCR also occurred (as determined below) at the same time.

DCR_scan: This QA indicator is the scan in each granule in which a DC restore occurred. There shall be 8 values per granule corresponding to modules M3 through M10. DCR is not performed on modules M1, M2, M11 or M12. This value is extracted from the telemetry word DpPvDcRstore as defined in reference 4. It is required to assign the indicator to the scan containing the space view 1 where the DCR occurs.

6.3 Radiometric Offset, a_o (Polarization Correction)

6.3.1 Algorithm

Analysis of the physics of the AIRS scanning approach has determined that the AIRS will experience a radiometric offset modulation proportional to the amount of polarization of the scan mirror and the spectrometer that will be scan angle dependent. This modulation has been confirmed with pre-flight testing (reference 5). The radiometric equation presented here has changed since the writing of this reference, but not sufficiently to change the outcome of the correlation of the scan angle dependence with the polarization effect. The offset has been determined to be

$$a_o(\theta_j) = N_m \bullet p_r p_t \bullet [\cos 2(\theta_j - \delta) + \cos 2\delta]$$

where

$a_o(\theta_j)$ = Scan angle dependent offset due to polarization (mW/m^2-sr-cm^{-1})

N_m = Radiance of a Unity Emissivity Surface at the Scan Mirror Temperature, T_{sm} obtained from the telemetry as indicated below and the Planck blackbody equation and the spectral coefficient file.

$p_r p_t$ = Product of the polarization factor of the scan mirror and spectrometer respectively. (dimensionless)

θ_j = Angle of the scan mirror for the jth footprint (0° is nadir)

δ = Phase of the polarization of the AIRS spectrometer.

6.3.2 Required Inputs

The following inputs are required to process the polarization offset and the QA indicators.

T_{sm} = The scan mirror temperature obtained from the telemetry 2766_ScMirrorTemp. No correction is to be made for the emissivity of the mirror. This is included in the $p_r p_t$ term.

ΔT_{sm} = Correction of scan mirror temperature.

$P_r p_t$ = Product of the polarization factor of the scan mirror and spectrometer respectively. This is provided as a file to be read by the L1B. It is based on analysis of polarization and radiometric data obtained during pre-flight testing (reference 5).

θ_j = Angle of the scan mirror for the jth footprint as obtained directly from the telemetry FpScanAng as indicated in Table 5.

δ = Phase of the polarization of the AIRS spectrometer. This term is provided in the same table as the $p_r p_t$ term.

ν = Center frequencies of all channels used in the calculation of radiance

6.3.3 QA indicators Output

The offset correction is only a function of the input data and the scan mirror temperature. We need only characterize the **scan mirror temperature** as defined above to assess instrument effects on this term. No

additional QA indicators are required. We can verify the proper implementation of the equation with the L1B validation.

6.4 OBC Gain, a_1, Determination

6.4.1 Algorithm

The gain is the first order responsivity of the AIRS in terms of radiance units (mW/m^2-sr-cm^{-1}) per digital number (dn) measured from the instrument. We calculate the gain as follows (see references 7 and 8).

$$a_{1,i} = \frac{N_{OBC,i}(1 + p_r p_t \cos 2\delta) - a_o(\theta_{OBC}) - a_2(dn_{obc,i} - dn_{sv,i})^2}{(dn_{obc,i} - dn_{sv,i})}$$

where the new terms are

$a_{1,i}$ = Gain of the AIRS per scan in units of Radiance per digital number, (N/dn).
$N_{OBC,i}$ = Radiance of the on-board calibrator blackbody (OBC BB) as calculated below.
$a_o(\theta_{OBC})$ = Radiometric offset evaluated at the angle of the scan mirror while viewing the OBC (180°) per the equation defined in the previous section. Units of Radiance, N.
a_2 = Second order coefficient as obtained from pre-flight testing (N/dn^2)
$dn_{obc,i}$ = OBC Blackbody digital number for the ith scan

6.4.2 OBC Radiance Determination

The OBC Radiance must be calculated using the 4 thermistors and the properties of the surrounding region (scan cavity) in order to give the most accurate calibration. The radiance of the OBC, $N_{OBC,i}$ is calculated as follows:

$$N_{OBC,i} = \varepsilon_{OBC} \, P(T_{OBC,i})$$

where ε_{OBC} is channel dependent from lookup tables, and T_{OBC} is a single values for all channels calculated as follows:

$$T_{OBC} = \tau_1 T_1 + \tau_2 T_2 + \tau_3 T_3 + \tau_4 T_4 + \tau_5 T_5$$

where $T_{1,2,3,4}$ are obtained from the instrument telemetry defined in Table 7. T_5 (a calibration temperature offset), and $\tau_{1,2,3,4,5}$ (weights for each temperature sensor) are obtained from the L1B Input Parameters file (l1b_params.txt). The approach to calculating the OBC blackbody radiance allows for turning off or failure of the OBC heater.

Table 7: Telemetry used in the calculation of the OBC radiance

Name	High Rate Engineering Data Identification
T_1	CaBbTempV1
T_2	CaBbTempV2
T_3	CaBbTemp3
T_4	CaBbTemp4

Note: The determination of use of A vs B requires examination of the ChPowerV0A and ChPowerV0B engineering values. The side used has ChPowerV0A (or ChPowerV0B) > 4.2. This algorithm is performed in the L1A PGE and therefore side selection is not required in the L1B PGE.

6.4.3 QA Indicators Output

gain: This QA indicator provides the gain, a_1, for the 51 reference channels for each scan line. This is the direct calculation of gain as determined in the equation above. (51 x 135 / granule)

gain_stats: This QA indicator provides statistics for all 2378 channels on the gain, a_1, over all scans in the granule. This indicator is of type "unlimited" engineering structure. (2378 / granule).

input_bb_counts: This QA indicator provides limit checking on the counts, dn_{OBC}, in the blackbody view. It is of type "limited" engineering structure (2378 / granule).

input_bb_signals: This QA indicator provides limit checking on the signals of the blackbody view. It is of type "limited" engineering structure (2378 / granule).

input_bb_temp: This QA indicator provides limit checking and stability checking on the as-calculated OBC temperature, T_{OBC}. It is of type "limited" engineering structure (1 / granule).

input_bb_temp1,2,3,4: These 4 QA indicators provides limit checking on the telemetered OBC temperature as defined in table 7. They are of type "limited" engineering structure (1 each / granule).

6.5 Noise Determination

6.5.1 Algorithm

One of the QA indicators to be output for the gain is a measure of the system noise, or Noise Equivalent Radiance (NEN). The **NeN** is reported for an assumed scene temperature of 250 K. The algorithm for determining the NEN is as follows:

$$\textbf{NeN} = \text{gain} \times \text{sqrt}(N_{250}/N_{Tbb} \times (\text{Noise}_{bb}^2 - \text{Noise}_{sv}^2) + \text{Noise}_{sv}^2)$$

Where,

Gain = **gain_stats.mean**,

N_{250K} = Planck blackbody radiance at 250K for each channel,

N_{Tbb} = **input_bb_temp.mean**,

Noise_{sv} = mean(**input_space_signals.dev**),

Noise_{bb} = **input_bb_signals.dev**.

6.5.2 Required Inputs

ε_{OBC} = Gain correction term (effective emissivity). This term comes from observation of the OBC blackbody simultaneously with the LABB during ground testing. The gain correction term is available in a text file for every channel.

ε_{CAV} = Cavity emissivity. This term allows the insertion of any anomalous geometric viewfactor effects. At the time of this writing there were none and this term will most likely be zero, however the correction term is available in a text file for every channel in the event it is needed..

a_2 = Second order coefficient as obtained from pre-flight testing (N/dn^2). This term is available in a text file and is the same term defined above in the calibration equation

T_5 = Calibration offset Temperature for the OBC blackbody. From pre-flight testing we have seen this number to be approximately +0.3K. This number corrects for the calibration of the temperature sensors $T_{1,2,3,4}$ by using the LABB. The number is available in a text file.

18

$\tau_{1,2,3,4,5}$ = Weighting of the OBC temperature sensor contributions. These numbers are determined from pre-flight testing and are available in a text file.

ν = Center frequencies of all channels used in the calculation of radiance

snr_fac = Correction factor to be multiplied by the measured SNR at 308K from the gain to obtain the SNR at the desired reporting temperature of 250K.

bb_counts_hi = Maximum allowable counts on the OBC BB for each channel

bb_counts_low = Minimum allowable counts on the OBC BB for each channel

bb_temp_hi = Maximum allowable temperature of the OBC BB (1 value)

bb_temp_low = Minimum allowable temperature of the OBC BB (1 value)

nen _hi = Maximum NEN allowed for each channel

nen _low = Minimum NEN allowed for each channel

6.5.3 QA indicators Output

NEN: This QA indicator provides the NEN for all 2378 channels as defined in the above equation. This NEN is to be compared to limits found in the l1b_limits.txt file and in the event an out of limit condition occurs in the granule, the CalChanSummary bit will be set as indicated.

6.5.4 L1B Radiometric Input Files

The input data defined above have been placed in a set of files used for the L1B testbed. These files, given in Table 8 represent the format in which L1B input data will be presented by the AIRS Calibration Team. The L1B PGE developers will convert these files to the necessary format to be read by the L1B PGE if necessary.

Table 8. Radiometric input files provided by the AIRS Calibration Team for use in the L1B PGE

Function	Filename	Ref	Contains
Radiometric Calibration Coefficients	labb_coefs.txt	7	a0 a1 a2 from LABB tests
OBC Gain Correction Factor	obc_emis.txt	7	Effective Emissivity from LABB tests
Polarization Correction	pol_coefs.txt	6	Polarization of spectrometer and scan mirror
Spectral Channels	spectral_coefs.txt	12	Center Freq BW etc.
Calibration Properties	cal_props.txt	12	Spatial, Spectral, Radiometric Quality Indicators from Pre-flight testing; AB States
L1B Input parameters	l1b_params.txt	-	Necessary input parameters not defined in the coefficients or limits file. No per-channel statistics
Per Channel Limits	l1b_limits.txt	-	Per-Channel Limits on the OBC, SV and EV DNs, NEdNs and NENs.

7   Spectral Requirements

Spectral calibration of the AIRS instrument is performed by the Level-1B PGE once per granule, and is output as part of the Level-1B standard radiance product. What follows is a description of the requirements for that spectral calibration processing.

7.1 Upwelling Radiance Fitting

Primary AIRS spectral calibration is performed by comparing observed upwelling radiance spectra against pre-calculated radiance spectra which are oversampled relative to the AIRS spectral resolution. The following sections describe in detail how this is done.

7.1.1 Static Data Ingest

In addition to the instrument radiances and information hard-coded in the spectral processing software, the spectral processing software also needs data from three static sources: The focal plane model, the upwelling spectral features database, and the channel properties file.

7.1.1.1 Focal Plane Model

The concept of fitting upwelling spectral features (at known spectral frequencies) to positions on the AIRS focal plane assembly requires knowledge of the positions of each detector element relative to the others. These details, as well as information about the spectrometer design, are contained in the Focal Plane Model file.   Table 9 provides the parameters given in the Focal Plane Model file

Table 9. Input parameters provided in the Focal Plane Model file.

Parameter	Number	Description
first_chan	17	The first channel number in each array
last_chan	17	The last channel number in each array
gr_const	1	The spacing between grating rulings, in microns
pitch	1	The spacing between adjacent detector elements, in microns
foc_len	17	The effective focal lengths of each detector array, in microns
order	17	The grating order of each array
alpha	17	The incidence angle for the grating illumination seen by each detector array
offset	17	The offset (relative to the nominal optical axis, in the along-dispersed direction) to the center of the first (lowest frequency) detector of each array
quadm	17	The amplitude of the empirical quadratic correction factor for each array
quadoff	17	The center frequency of the empirical quadratic correction factor for each array, in wavenumbers

7.1.1.2 Upwelling Spectral Features

An Upwelling Spectral Features data file provides all the information necessary to characterize the upwelling features and how to fit to them. The following parameters are provided in the Upwelling Spectral Features data file.

1) A numbered list of atmospheric conditions present in the file;
2) A specification for which atmospheric condition is supposed to be applied under which conditions; (the required information is listed in section 7.1.2).
3) The number of spectral features to be considered (for each climatology);
4) The reference frequency of the feature (for each feature, for each climatology);
5) The required contrast for the feature to be deemed clear (for each feature, for each climatology);
6) The weight to be applied to the feature (for each feature, for each climatology);
7) The required feature position accuracy, or fit residual (for each feature, for each climatology);
8) The range of channels which cover this feature (for each feature, for each climatology);
9) The number of offsets at which radiances are calculated (for each feature, for each climatology);
10) The offset at which the radiances were calculated (for each offset, for each feature, for each climatology); and

11) The radiances themselves (for each channel in range, for each offset, for each feature, for each climatology).

7.1.1.3 Calibration Properties

The Calibration Properties file contains a quantitative assessment of the quality of each channel, known as 'A/B state'. A/B state (for each of the 2378 channels) is in the range from 0 (best) to 6 (worst). Table 8 identifies the Calibration Properties filename.

7.1.2 "Climatology" Selection

The radiances in the upwelling spectral features database are, of course, dependent on the atmospheric state or condition for which they were calculated. In order to determine which radiances in the upwelling spectral features database against which to compare observations, it is therefore necessary to determine (crudely) the atmospheric state being observed. This crude determination is referred to as climatology selection.

7.1.2.1 Outputs

The only output from this processing is a determination of which atmospheric state best represents the current granule. This is reported as an integer in **spec_clim_select**. **spec_clim_select** determines which data in the Upwelling Spectral Features file are used.

7.1.2.2 Required Inputs

1) LatGranCen, the latitude at the center of the granule (from L1A);
2) SolZen, the solar zenith angle, for each footprint being considered for spectral averaging (from L1A);
3) The season at the center of the granule, expressed as a floating point number of days since the start of January 1, current year (from L1A);
4) LandFrac, the land fraction, for each footprint being considered for spectral averaging (from L1A); and
5) The description of what climatology to use for each possible atmospheric condition (from the Upwelling Features file).

7.1.2.3 Algorithm

"Climatology State" is determined by:

1) Whether a footprint is over land or sea;
2) What latitude the measurement was made at;
3) Whether it's day or night; and
4) What season the observation is during.

Because each of these parameters is specified on a per-footprint basis, and because the climatology selection is done on a per-granule basis, further clarification is provided below.

An average land/sea fraction is to be calculated as the average of the landFrac values for those footprints containing at least one clear spectral feature. If this average is greater than or equal to 0.5, then the granule is to be considered a land granule; otherwise, the granule is to be considered a sea granule.

The granule's latitude will be taken to be LatGranCen.

Whether a footprint is day or night is determined by that footprint's solar zenith angle ("solzen"). If that angle is less than 90.25 degrees, then that footprint is deemed to be a day footprint. If at least half of the footprints containing at least one clear spectral feature are determined to be day footprints, then the granule shall be considered a day granule; otherwise, the granule shall be considered a night granule.

The granule's season will be specified as the day-of-year count at the center of the granule, $0 <= \text{season} <= 366$.

Taken together, these four parameters identify a point in four-dimensional space; the upwelling features file must specify which four-dimensional volume element is associated with which atmospheric state. An algorithm must be applied here to determine in which 4-D volume element the current granule lies.

7.1.2.4 QA Indicators

spec_clim_select: The atmospheric state against which to compare, represented as an integer;

SpectralFeaturesUpwell: Though not really a QA indicator, this is output as part of the standard AIRS L1B product, and is determined by **spec_clim_select**, and data in the Upwelling Spectral Features file.

7.1.3 Clear Feature Identification and Averaging

Only those spectral features having sufficient spectral contrast are fit to. Sections 7.1.3.1 – 7.1.3.4 show how this is determined, and what outputs are produced.

7.1.3.1 Outputs

For each of the features being used for the current climatology (see sections 7.1.1.2 and 7.1.2), an average spectrum is produced. These spectra are passed to the correlation algorithm (discussed in section 7.1.4 and following).

7.1.3.2 Required Inputs

1) Radiances for each footprint being considered (from L1A);
2) The list of spectral features to be used (from the Upwelling Spectral Features file), for the current climatology;
3) The channel range associated with each spectral feature (from the Upwelling Spectral Features file);
4) The required spectral contrast for each spectral feature (from the Upwelling Spectral Features file);
5) Channel 'A/B state' (from the Channel Properties file).

7.1.3.3 Algorithm

The spectral contrast of a feature, as seen in a single footprint, is defined as the absolute value of the difference between the maximum and minimum radiance of "A/B state is good" channels associated with that feature. That is, determine the range of channels associated with this feature, for this climatology. Of those channels, consider radiances only from channels which have A/B state ≤ 2 (the good channels). The spectral contrast, then, is the maximum of those radiances, minus the minimum of them.

For each near-nadir footprint being considered, calculate the contrast of each feature. If the spectral contrast is equal to or greater than the required spectral contrast for that feature, then add that feature's radiances to a buffer, and increment the count of spectra in the buffer.

Finally, calculate the mean spectrum of each clear feature by dividing the summed radiances in the buffers by the number of spectra co-added.

7.1.3.4 QA Indicators

spec_feature_contrast_stats: This is a set of limited engineering structures, one structure for each spectral feature. The statistics are calculated over each near-nadir footprint considered. The engineering structure is "limited" (limit checked) to count the number of footprints satisfying the contrast criteria.

7.1.4 Spectral Feature Correlations

The average feature spectra calculated in section 7.1.3 are compared against pre-calculated spectra sampled at frequencies corresponding to small translations of the focal plane. By correlating the averaged spectra against these pre-calculated spectra, we find the apparent translation of the focal plane which is most consistent with this feature's spectrum.

7.1.4.1 Outputs

For each spectral feature being considered, a displacement, in microns, is produced. These displacements ("$\{y_0\text{'s}\}$") are passed to the focal plane fitting algorithm, described in section 7.1.5.

7.1.4.2 Required Inputs

1) Averaged radiance spectra from section 7.1.3, above.
2) Channel 'A/B state' (from the Channel Properties file).
3) The number of offsets at which radiances are calculated (for each feature, for each climatology);
4) The offsets at which the radiances were calculated (for each offset, for each feature, for each climatoloty); and
5) The radiances themselves (for each channel in range, for each offset, for each feature, for each climatology).

7.1.4.3 Algorithm

The spectral feature correlation fitting has two components: the calculation of the correlation coefficients (corresponding to correlations at different focal plane shifts), and the determination of the focal plane shift corresponding to the maximum of these correlations.

7.1.4.3.1 Correlation Coefficient Calculation

For a given spectral feature, for a given climatology, the averaged spectrum is to be correlated against radiances corresponding to each offset for that feature. That is, for each of the feature's focal plane shifts, a correlation is to be calculated. For two sets of samples samples $\{X_i\}$ and $\{Y_i\}$ (with the same number of points), the Pearson's correlation coefficient between the two samples is given by:

$$\rho = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{[\sum (x_i - \bar{x})^2][\sum (y_i - \bar{y})^2]}}$$

In this case, the Pearson equation is applied once for each shift, but the sums are calculated only over those channels (in range for the feature) which have state ≤ 2.

7.1.4.3.2 Correlation Coefficient Fitting

Once the individual correlations (corresponding to each shift) have been calculated, a quadratic is fit to them, in a least-squares sense, using the offsets as the independent variable and the correlations as the

dependent variable. Once the data have been fit to the equation $y = ax^2 + bx + c$, the offset corresponding to the maximum is given by:

$$\text{Offset of Max} = -b/(2a),$$

7.1.4.4 QA Indicators

spec_feature_shifts_upwell: This is the primary indicator of the feature correlation processing, and is simply the offset (in microns) corresponding to the maximum of the correlation function. It is reported once per granule, for each upwelling spectral feature.

spec_feature_corr_upwell: This is the peak value of the quadratic that was fit to the feature correlations. That is, it is an estimate of what the correlation would have been if a pre-calculated spectrum had been available at exactly the offset calculated. It is given by $max = c - b^2/4a$, and should be just less than one. It is reported once per granule for each upwelling spectral feature.

spec_feature_sharp_upwell: This is an indicator of the sensitivity of this spectral feature to shifting. It is a measurement of the sharpness of the correlation-versus-offset curve. It is simply given by **a**, the quadratic coefficient in $y = ax^2 + bx + c$, from section 7.1.4.3.2.

7.1.5 Focal Plane Position Fitting

The positions (offsets) calculated in section 7.1.4.3.2 are fed into a global minimization routine to find the best fitting position of the focal plane as a whole.

7.1.5.1 Outputs

The two outputs from this process are two focal plane-wide translations, one in the along-dispersed direction, the other in the along-focus direction. The along-dispersed position is reported in the standard product as **spec_shift_upwell**, and the along-focus shift added to the nominal focal length is reported as **spec_fl_upwell**.

7.1.5.2 Required Inputs

1) All eleven parameters from the focal plane map;
2) The feature frequencies, from the Upwelling Spectral Features file;
3) The feature weights, from the Upwelling Spectral Features file;
4) The feature position shifts, as calculated above, in section 7.1.4

7.1.5.3 Algorithm

The focal plane fit is done by adjusting two parameters (shift, in the along-dispersed and along-focus directions) to minimize (in a least-squares sense) the differences between calculated and known feature ferquencies. Step-by-step, this is how that is done:

1) Delta focal length and delta offset are used as the two parameters of a 2-dimensional adaptive simplex method (2-D amoeba).
2) Use as the metric to be minimized:

$$M = \sum_{features} w_i (\nu_{calc} - \nu_{no\,min\,al})^2$$

Where $w(i)$ = the weight of feature i, from the upwelling spectral features file;

$\nu_{no\,min\,al}$ = the nominal frequency of the feature, as reported in the upwelling spectral features file; and

ν_{calc} = the feature's observed frequency, as calculated from the grating model (ATBD reference) and the focal plane map.

3) The two parameters to be fit to (along-focus displacement and along-dispersed displacement) are the ΔF in equation 4.2 of the ATBD, and Δy_0 in equation 4.3, respectively. To equation 4.2 is added the observed position translation from section 7.1.4, above.

4) For the uncertainties of ΔF and Δy_0, only the contributions from the fit itself will be reported. They will be calculated as the span of the simplex, in each direction, at the time of the final amoeba iteration. That is, for this 2-dimensional simplex fit, they will be the differences between the minimum and maximum of the two deltas, as calculated over the three vertices of the bounding simplex.

5) If amoeba does not converge, set the Spectral Quality Bad bit in **CalChanSummary**, for each channel.

7.1.5.4 QA Indicators

In addition to **spec_shift_upwell** and **spec_fl_upwell** (listed above, under "output"), the following QA indicators are also produced:

spec_shift_unc_upwell: The uncertainty in the fit of the along-dispersed translation;

spec_fl_unc_upwell: The uncertainty in the fit of the along-focus translation;

spec_iter_upwell: The number of iterations run by amoeba before the convergence criterion was met;

spec_feature_resid_upwell: The residuals, in wavenumbers, between the calculated and known frequencies for each feature: $\left| v_{calc} - v_{no\,min\,al} \right|$, using the ΔF and Δy_0 calculated above. If any feature's residual is greater than freq_unc for that feature, set the Spectral Calibration Bad bit in **CalChanSummary** for all channels in the module containing the "offending" feature.

7.1.6 Frequency Calculation

The parameters calculated in section 7.1.5 are used in combination with the focal plane model to determine the actual frequencies of the AIRS channels.

7.1.6.1 Outputs

The following parameters are produced as output from the frequency calculation:

spectral_freq: The frequencies of the AIRS channels, as calculated for this granule;

spectral_freq_unc: The uncertainty for each of the **spectral_freq**'s;

nominal_freq: The nominal frequencies of the AIRS channels;

spectral_freq_prev: The frequencies of the AIRS channels, as calculated for the previous granule;

spectral_freq_prev_unc: The uncertainty for each of the **spectral_freq_prev**'s;

spectral_TAI: The time of the spectral calibration for this granule; and

spectral_TAI_prev: The time of the spectral calibration for the previous granule.

7.1.6.2 Required Inputs

1) All eleven parameters from the focal plane map;

2) The ΔF and Δy_0, as calculated above, in section 7.1.5;

3) Feature residual limits, from the Upwelling Spectral Features file;

4) Information from the previous granule, if available: **spectral_TAI**, **spectral_freq**, and **spectral_freq_unc**.

5) **end_Time**, from Level-1A.

7.1.6.3 Algorithm(s)

spectral_freq: If amoeba converged, apply the grating equation (with the terms ΔF and Δy_0 added) to each detector in the focal plane. Report the resultant frequencies. If amoeba did not converge, use **spectral_freq** from the previous granule, if that granule is available. If amoeba did not converge, and the previous granule is not available, use **nominal_freq**.

spectral_freq_unc: If amoeba converged, and if all features were fit to within the required feature residual limits, report the uncertainties from the Focal Plane Map file, assigning the per-module uncertainties to each channel. If amoeba converged, and one or more features was not fit to within the required feature residual limits, set **spectral_freq_unc** to the root sum square ("RSS") of freq_unc and the worst residual in the module. If amoeba did not converge, and the previous granule is available, use two times **spectral_freq_unc** from the previous granule. If amoeba did not converge, and the previous granule is not available, use five times freq_unc.

nominal_freq: Apply the grating equation (with the terms ΔF and Δy_0 set to zero) to each detector in the focal plane.

spectral_freq_prev: If the previous granule is available, **spectral_freq** from that granule. If the previous granule is not available, zeroes.

spectral_freq_prev_unc: If the previous granule is available, **spectral_freq_unc** from that granule. If the previous granule is not available, zeroes.

spectral_TAI: **end_Time**, from Level-1A.

spectral_TAI_prev: : If the previous granule is available, **spectral_TAI** from that granule. If the previous granule is not available, zero.

7.1.6.4 QA Indicators

Other than the seven output parameters listed above (section 7.1.6.1), there are no QA indicators associated with the actual frequency calculation.

7.2 Parylene Fitting

Secondary AIRS spectral calibration is performed by comparing observed radiance spectra of the Onboard Spectral Calibrator (OBS) aginst precalculated radiance spectra which are oversampled relative to the AIRS spectral resolution. The following sections describe in detail how this is done. This secondary spectral calibration is only used as a diagnostic, for verification's sake. Consequently no frequencies are calculated or reported as output from this secondary spectral calibration.

7.2.1 Static Data Ingest

In addition to the instrument radiances and information hard-coded in the spectral processing software, the spectral processing software also needs data from three static sources: The focal plane model, the parylene spectral features database, and the channel properties file.

7.2.1.1 Focal Plane Model

The Focal Plane Model input for the parylene fitting is identical to that input for fitting to upwelling radiance features. See section 7.1.1.1 for more information.

7.2.1.2 Parylene Spectral Features

A Parylene Spectral Features data file provides all the information necessary to characterize the parylene features and how to fit to them. The following parameters (referred to later in this section) are provided in the Parylene Spectral Features data file:

1) The number of spectral features to be considered;
2) The reference frequency of the feature (for each feature);
3) The weight to be applied to the feature (for each feature);
4) The required feature position accuracy, or fit residual (for each feature);
5) The range of channels which cover this feature (for each feature);
6) The number of offsets at which radiances are calculated (for each feature);
7) The offset at which the radiances were calculated (for each offset, for each feature);
8) The radiances themselves (for each channel in range, for each offset, for each feature);

7.2.1.3 Calibration Properties

The Calibration Properties file is the same as that described in section 7.1.1.3. See that section for a description.

7.2.2 Feature Averaging

Unlike the upwelling fitting, there are no contrast criteria. Features from all parylene footprints (OBS views) are to be averaged.

7.2.2.1 Outputs

For each of the features being used, an average spectrum is produced. These spectra are passed to the correlation algorithm (discussed in section 7.2.3.3 and following).

7.2.2.2 Required Inputs

1) Radiances for each OBS footprint;
2) The list of spectral features to be used (from the Parylene Spectral Features file);
3) The channel range associated with each spectral feature (from the Parylene Spectral Features file);
4) Channel 'A/B state' (from the Channel Properties file).

7.2.2.3 Algorithm

Simply add together, frequency by frequency, the radiances for a feature from all well-calibrated OBS footprints. Divide by the number of footprints present.

7.2.2.4 QA Indicators

ave_pary_spectrum: This is the average parylene spectrum. It covers all 2378 AIRS channels.

7.2.3 Spectral Feature Correlations

The average feature spectra calculated in section 7.2.2 are compared against pre-calculated spectra sampled at frequencies corresponding to small translations of the focal plane. By correlating the averaged spectra against these pre-calculated spectra, we find the apparent translation of the focal plane which is most consistent with this feature's spectrum.

7.2.3.1 Outputs

For each spectral feature being considered, a displacement, in microns, is produced. These displacements ("$\{y_0$'s$\}$") are passed to the focal plane fitting algorithm, described in section 7.1.5.

7.2.3.2 Required Inputs

1) Averaged radiance spectra from section 7.2.2 above;
2) Channel 'A/B state' (from the Calibration Properties file);

3) The number of offsets at which radiances are calculated (for each feature);
4) The offset at which the radiances were calculated (for each offset, for each feature);
5) The radiances themselves (for each channel in range, for each offset, for each feature).

7.2.3.3 Algorithm

The spectral feature correlation fitting has two components: the calculation of the correlation coefficients (corresponding to correlations at different focal plane shifts), and the determination of the focal plane shift corresponding to the maximum of these correlations.

7.2.3.3.1 Correlation Coefficient Calculation

For a given spectral feature the averaged spectrum is to be correlated against radiances corresponding to each offset for that feature. That is, for each of the feature's focal plane shifts, a correlation is to be calculated. For two sets of samples samples $\{X_i\}$ and $\{Y_i\}$ (with the same number of points), the Pearson's correlation coefficient between the two samples is given by:

$$\rho = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{[\sum (x_i - \bar{x})^2][\sum (y_i - \bar{y})^2]}}$$

In this case, the Pearson equation is applied once for each shift, but the sums are calculated only over those channels (in range for the feature) which have state ≤ 2.

7.2.3.3.2 Correlation Coefficient Fitting

Once the individual correlations (corresponding to each shift) have been calculated, a quadratic is fit to them, in a least-squares sense, using the offsets as the independent variable and the correlations as the dependent variable. Once the data have been fit to the equation $y = ax^2 + bx + c$, the offset corresponding to the maximum is given by:

Offset of Max = -b/(2a),

7.2.3.4 QA Indicators

input_spec_counts: This is a "limited" engineering structure (similar to input_scene_counts, input_space_counts, and input_bb_counts) which provides statistics on the counts of the Parylene source.

spec_feature_shifts_pary: This is the primary indicator of the feature correlation processing, and is simply the offset (in microns) corresponding to the maximum of the correlation function. It is reported once per granule, for each upwelling spectral feature.

spec_feature_corr_pary: This is the peak value of the quadratic that was fit to the feature correlations. That is, it is an estimate of what the correlation would have been if a pre-calculated spectrum had been available at exactly the offset calculated. It is given by max $= c - b^2/4a$, and should be just less than one. It is reported once per granule for each upwelling spectral feature.

spec_feature_sharp_pary: This is an indicator of the sensitivity of this spectral feature to shifting. It is a measurement of the sharpness of the correlation-versus-offset curve. It is simply given by **a**, the quadratic coefficient in $y = ax^2 + bx + c$, from section 7.2.3.3.2.

7.2.4 Focal Plane Position Fitting

The positions (offsets) calculated in section 7.2.3.3.2 are fed into a global minimization routine to find the best fitting position of the focal plane as a whole.

7.2.4.1 Outputs

The two outputs from this process are two focal plane-wide translations, one in the along-dispersed direction, the other in the along-focus direction. The along-dispersed position is reported in the standard product as **spec_shift_pary**, and the along-focus shift added to the nominal focal length is reported as **spec_fl_pary**.

7.2.4.2 Required Inputs

1) All eleven parameters from the focal plane map;
2) All eleven parameters from the focal plane map;
3) The feature frequencies, from the Parylene Spectral Features file;
4) The feature weights, from the Parylene Spectral Features file;
5) The feature position shifts, as calculated above, in section 7.2.3

7.2.4.3 Algorithm

The focal plane fit is done using the same algorithm as provided in section 7.1.5.3.

7.2.4.4 QA Indicators

In addition to **spec_shift_pary** and **spec_fl_pary** (listed above, under "output"), the following QA indicators are also produced:

spec_shift_unc_pary: The uncertainty in the fit of the along-dispersed translation;

spec_fl_unc_pary: The uncertainty in the fit of the along-focus translation;

spec_iter_pary: The number of iterations run by amoeba before the convergence criterion was met;

spec_feature_resid_pary: The residuals, in wavenumbers, between the calculated and known frequencies for each feature: $\left| v_{calc} - v_{no\,min\,al} \right|$, using the ΔF and Δy_0 calculated above.

8   Spatial Requirements

The calibration of AIRS has been extensively tested during the pre-launch characterization (references 8 and 9). While the calibration for uniform scenes shows a calibration residual of less than 0.1K between 230K and 305K scenes, under non-uniform scene conditions some AIRS channels exhibit a scene contrast dependent offset, referred to as scene non-uniformity error ("Cij error"). If the thermal radiation in the AIRS FOV is not uniform, typically due to the presence of clouds, this error can be significant compared to the 0.1K residual observed under uniform illumination testing.

The AIRS spectrometer includes duplicate spectral coverage of three narrow spectral regions. Two of the three regions can be used to characterize each AIRS footprint for adequate spatial homogeneity directly, a third region can be used somewhat less directly. Three pairs of "overlap channels" and their properties are listed in Table 10. Reference 10 shows the spectral overlap regions for a tropical atmosphere. The "overlap channel" pairs were chosen for their good NEDT, reasonable SRF centroid overlay, their good spectral and radiometric calibration, and for their FOV centroid shift relative to the focal plane average centroid.

Table 10. Identification of cij QA indicator channel selection for L1B processing

QA Indicator Name	PGE Channel	LM Channel	SRF Centroid
			(cm^{-1})
Rdiff_lwindow_M9_chan	597	1781	847.837
Rdiff_lwindow_M8_chan	625	1753	856.342

Rdiff_swindow_M1a_chan	2280	98	2560.853
Rdiff_swindow_M2a_chan	2252	256	2560.460
Rdiff_strat_M1b_chan	2027	235	2310.456
Rdiff_strat_M2b_chan	2000	378	2310.524

The AIRS Calibration Team requires that the 6 PGE channel definitions given in Table 10 be placed in the L1B QA data file for every granule. Additionally, the calculated radiances, N, as defined in section 6 for pairs of the channels in Table 10 be differenced as follows and the results placed in the L1B data file. Since the radiances are defined for every footprint, the radiance differences are also to be provided for every footprint.

Rdiff_lwindow = N(Rdiff_lwindow_M8_chan) - N(Rdiff_lwindow_m9_chan) + water_offset

Rdiff_swindow = N(Rdiff_swindow_M1a_chan) - N(Rdiff_swindow_M2a_chan) + window_offset

Rdiff_strat = N(Rdiff_strat_M1b_chan) – N(Rdiff_strat_M2b_chan) + CO2_offset

where water_offset, window_offset, and CO2_offset are defined in the l1b_params.txt file.

Each of the differences are to checked to see if they are greater than some factor, N_Rdiff_*, times the RSS of the noise level of each of the channels. If they are, then the corresponding bit in the SceneInhomogenous word is to be set to high. The algorithm is as follows:

If

$$|Rdiff\_lwindow| \geq$$

$$N\_Rdiff\_lwindow \times \sqrt{NEN(Rdiff\_lwindow\_M8\_chan)^2 + NEN(Rdiff\_lwindow\_m9\_chan)^2}$$

then SceneInhomogenous(bit=6) = 1. Initially after launch, *N_Rdiff_lwindow* will be set to 5 however this may change after Launch.

Similarly for Rdiff_swindow and Rdiff_strat for bits 7 and 5 of SceneInhomogenous respectively.

9 VIS Requirements

The primary metrics for monitoring the radiometric calibration of the Vis/NIR system are the correction terms routinely generated from vicarious calibration against known ground targets and MODIS data. (See the Level 1b ATBD, Part 2 for a discussion, in particular, note the terms gamma-g and gamma-M in Eq. 2-15.) Each of these terms, as well as the final gain and offset, will be studied as a function of relevant independent variables (e.g. time, lattitude, longitude, etc). Furthermore, health of the on-board bulbs is monitored by trend analysis of the Kij terms described in the Level 1b ATBD, Part 2, Section 2.5.4.1. Table 11 lists all parameters routinely generated by the L1B that are expected to be useful in monitoring the Vis/NIR calibration.

Table 11. QA indicators used in monitoring Vis/NIR radiometric calibration

Variable	Frequency	Explanation
QAPercentBadData	1/Granule	Percentage of radiance data flagged bad

gain	1/Granule	Gain calculated for each detector
gain_err	1/Granule	Estimated error on the gain for each detector
gain_fit_dev	1/Granule	Deviation fit report for gain
K21	1/Granule	Counts observed from calibration bulb #2 divided by counts from bulb #1, for each detector
K32	1/Granule	Counts observed from calibration bulb #3 divided by counts from bulb #2, for each detector
K31	1/Granule	Counts observed from calibration bulb #3 divided by counts from bulb #1, for each detector
gamma_ground	1/Granule	Correction factor to internally calculated gain, based on observations of ground targets, for each detector
gamma_MODIS	1/Granule	Correction factor to internally calculated gain, based on comparison to MODIS data, for each detector
rad_stats	1/Granule	Statistics on scene radiance values, for each detector
rad_unc_stats	1/Granule	Statistics on radiance uncertainty, for each detector
offset_fit_dev	1/Granule	Deviation fit report for offset calculation
limit_offsets	1/Granule	Comparison of calculated offsets to limit values
offset_stats	1/Granule	Statistics on calculated offsets
offset_unc_stats	1/Granule	Statistics on offset uncertainty
offset	1/Scan	Offset for each detector, used in calibration equation
offset_err	1/Scan	Error in offset
NeN	1/Scan	Noise equivalent radiance for each detector
rad_unc	1/Scan	Radiance uncertainty from goodness–of–fit of calibration (excludes NeN and biases)
counts	1/Scan	Counts observed on the 6 calibration footprints, for each Vis/NIR detector

10 Engineering Telemetry Requirements

Level 1B telemetry processing provides summary data which is further processed by the Calibration Team, using matlab tools, to provide instrument health and status information to project team members. The main function of this software is to simplify the trending of the high rate engineering telemetry by pre-processing the L1A scan dependent data into granule level summary statistics. Two scenarios for processing are planned, (1) for normal science operations and (2) for special tests. For both (1) and (2), the granule level summary statistics shall be provided. For (2), Level 1A telemetry files by special test phase shall also be provided.

10.1 QA Indicators Output

Level 1A telemetry processing provides engineering telemetry data converted to engineering units, on a scan by scan basis. Level 1B processing shall generate, on a granule by granule basis, a limited engineering structure for the 517 useful parameters of engineering Packet 1 and the 384 useful parameters of engineering Packet 2 (each packet is zero filled to a word count of 2667, thereby resulting in non-useful values). The limited engineering structure is to be used for all 901 parameters. The data are to be stored in a separate L1B data product.

*One additional field is to be included in the L1B limited engineering structure for the telemetry data. The "median" is to be provided where the median is calculated over all values within the granule.

In addition, the further processing by the Cal Team will require the parameters, LonGranuleCen, LatGranuleCen, LocTimeGranuleCen, sat_lat, sat_lon, and nadirTAI for each granule.

The AutomaticQAFlag is to be defined as given in section 4.2.2 using the "state" provided from L1A, but not using the CalGranSummary algorithm.

10.2 Required Inputs

The limits (range_max and range_min) values will be provided in a single text file. This file is generated from an Excel worksheet, where range limits are adjusted by Cal Team members. The adjusted ranges are transferred to a second Excel worksheet, from which they are saved in a simple text format. Table 12 gives an example of such a table for 3 of the 901 parameters. The limit values will be somewhere between operational limits of "green" and "yellow". This sets them tighter than the operational limits to facilitate trending. All references to these limits shall identify them as "blue" to differentiate them from operational limits. This table will need to be updated periodically, depending on orbital conditions or temporal drifts. Hence, the Level 1B processing must accommodate periodic (weekly or monthly) updates to the range limits.

Table 12: Sample input range limits file

Parameter Seq. Number		Range_min	Range_max	Units
L1A / L1B No.	Database No.			
TBD	2672	5	30	Celsius
TBD	2673	5	30	Celsius
TBD	2674	5	30	Celsius

Appendix 1. L1B_AIRS_QA Interface Specification